GRACE-FO Science Results and Mission Status

EGU22-3672

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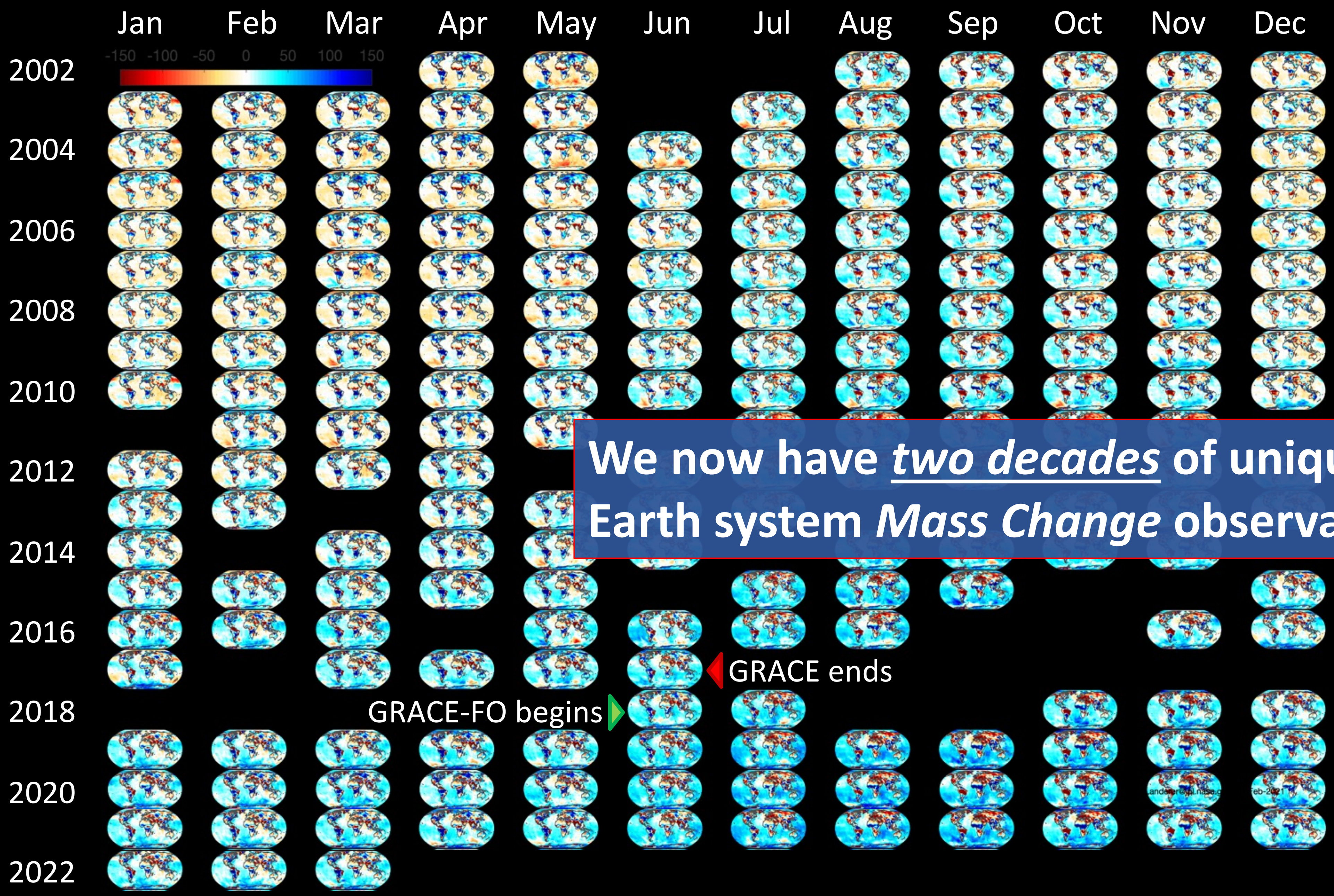
With support from CSR / GFZ / GSFC Science Data System Teams

GRACE and GRACE-FO: 20 years of Amazing Discoveries

Jet Propulsion Laboratory
California Institute of Technology



We now have *two decades* of unique monthly Earth system *Mass Change* observations!

GRACE and GRACE-FO: 20 years of Amazing Discoveries

Jet Propulsion Laboratory
California Institute of Technology

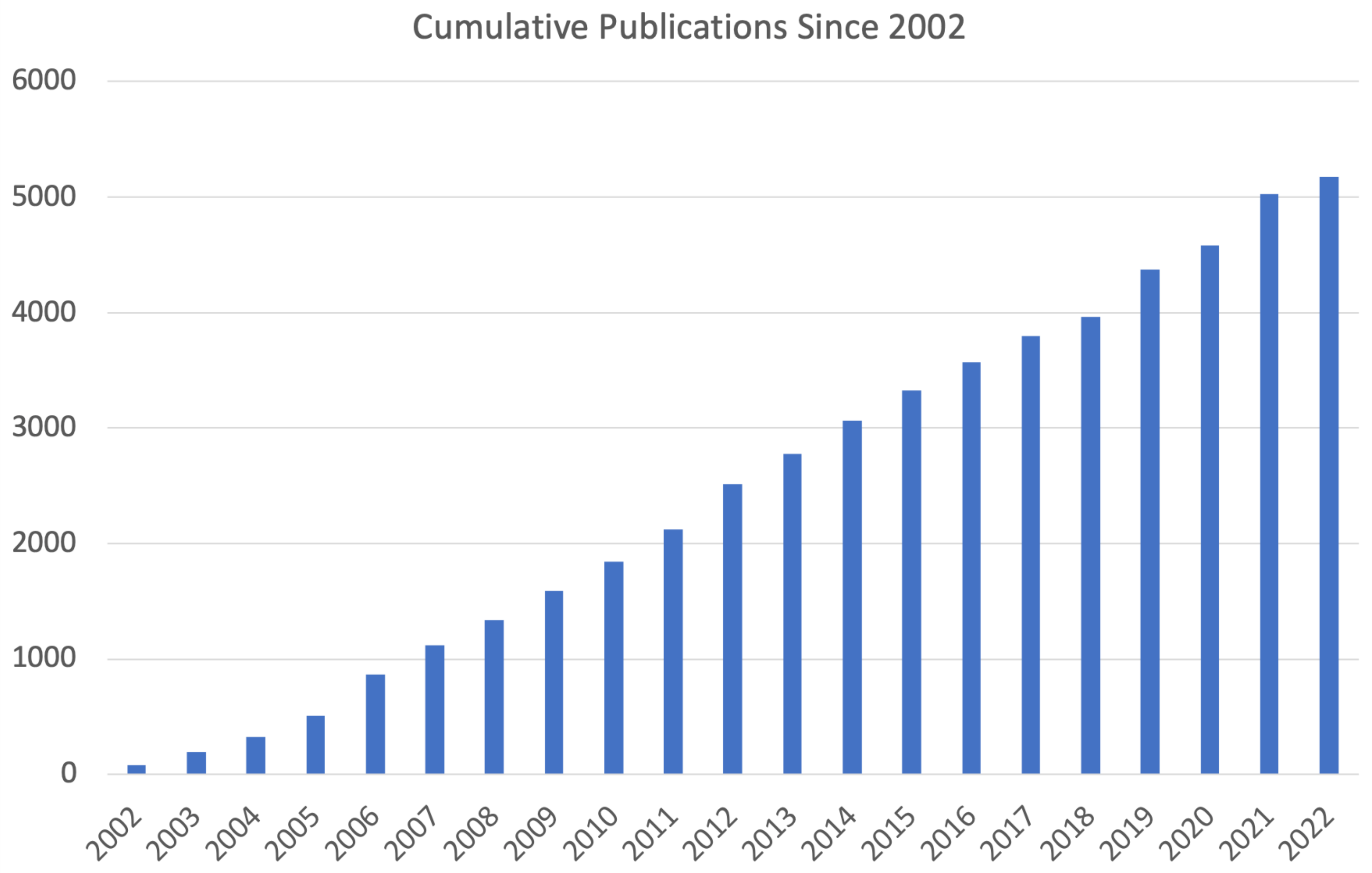
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Highlights:

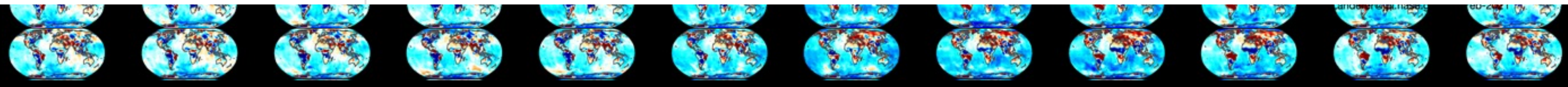
Publications: **5178**

2nd most cited NASA instrument/observable in the **IPCC AR6 report**

Terrestrial Water Storage (i.e., Mass Change) has recently been classified as a **GCOS Essential Climate Variable** and contributes to 14 of 54 additional GCOS Essential Climate Variables

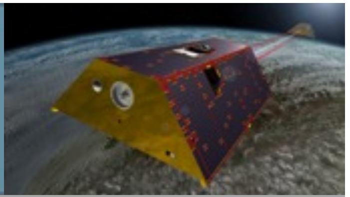


2020



2022

GCOS 2022: *Terrestrial Water Storage (TWS)*
will be implemented as a new ECV



Public Review of the new Global Climate Observing System (GCOS) 2022 Implementation Plan

GCOS invites all interested experts **to review the GCOS Implementation Plan** by **Friday 3 June 2022.**

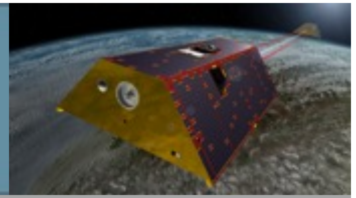
This plan also includes ***Terrestrial Water Storage (TWS) as a new ECV.***

This report aims to guide the development and improvement of the global climate observing system.

To participate in the review:
https://apps.ipcc.ch/comments/gcos/fod/register.php

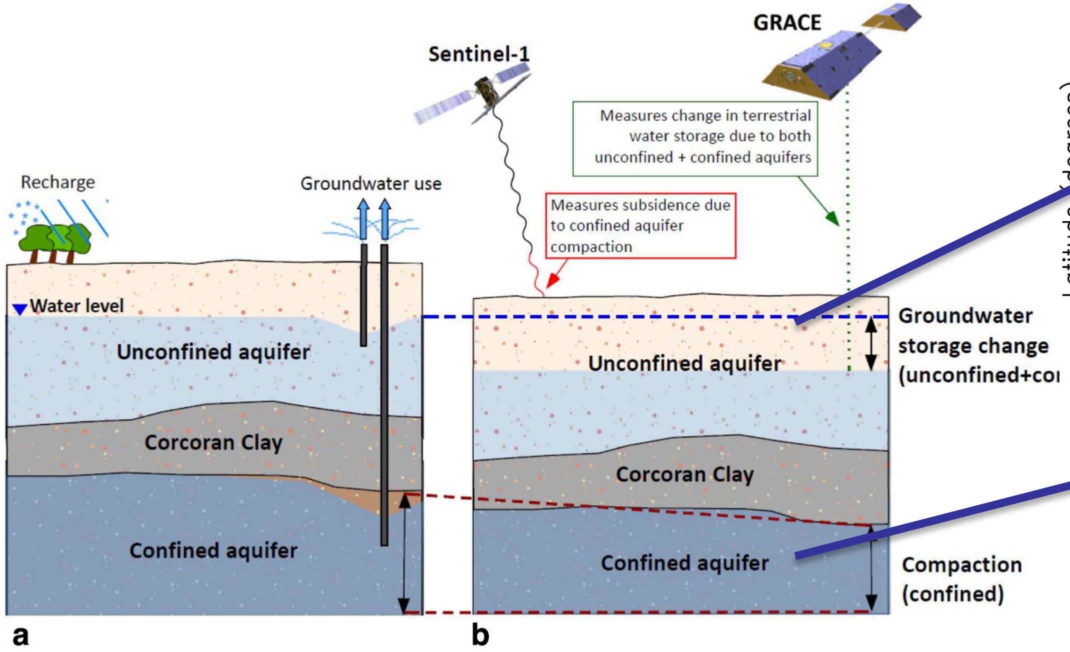
Contact: Andreas Güntner (andreas.guentner@gfz-potsdam.de)

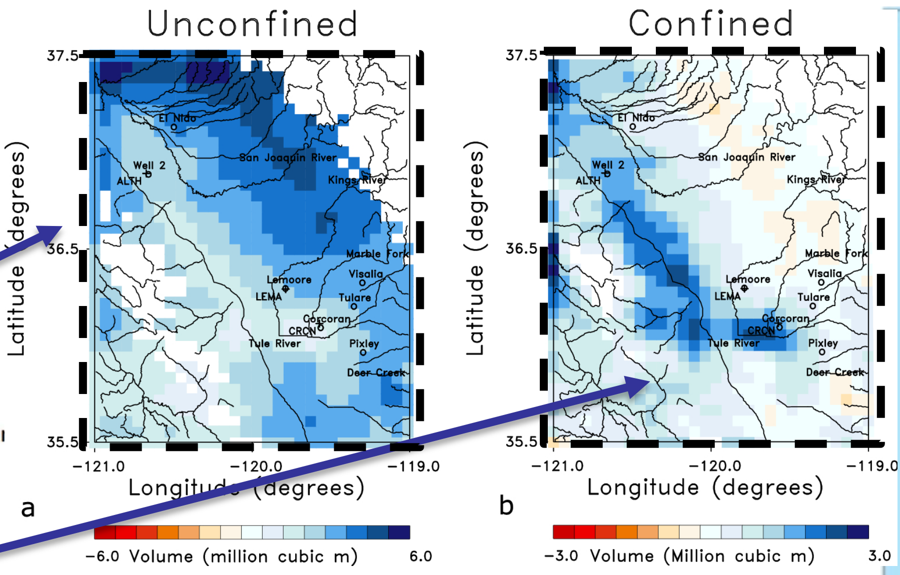
Using Sentinel-1 and GRACE(-FO) satellite data to monitor the hydrological variations within the Tulare Basin, California

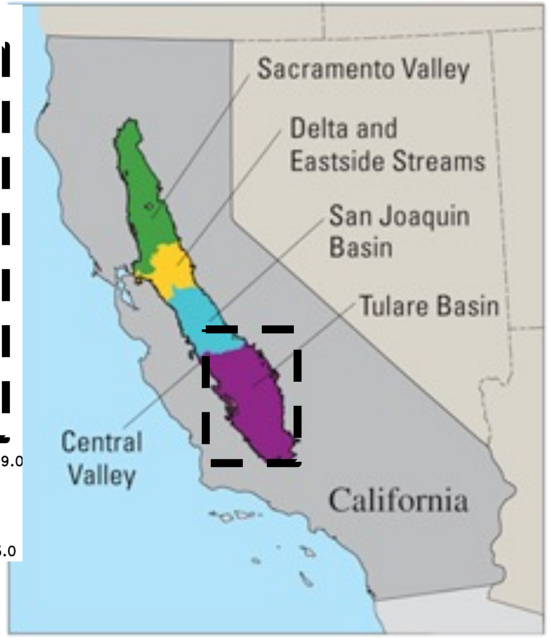


Vasco et al., 2022, https://doi.org/10.1038/s41598-022-07650-1

- GRACE-FO & InSAR (e.g., Sentinel-1) combination can improve groundwater management.
- Information on how much underground water loss comes from confined *vs.* unconfined aquifers.



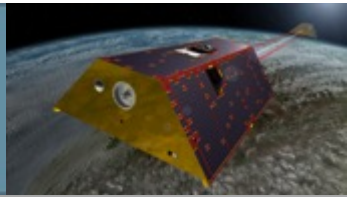




Aquifers are confined by layers of stiff, impermeable clay, whereas unconfined soil is looser. When water is pumped from an aquifer, the clay takes a while to compress in response to the weight of land mass pressing down from above. Unconfined soil, on the other hand, rises or falls more quickly in response to rain or pumping. By combining satellite measurements of surface deformation (InSAR) with those of mass changes (GRACE-FO) in a computer model, water mass changes in the shallow unconfined aquifer and in the underlying confined aquifer can be identified.

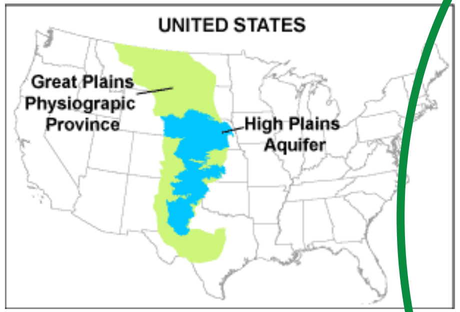
In the winter of 2018–2019, uplift is observed at the confluence of several rivers and streams that drain into the southeastern edge of CA's Tulare basin. The quick and effective synthesis of InSAR and GRACE-FO data revealed where, and by how much, the shallow and deep aquifers filled.
The new model can be repurposed to represent other agricultural regions where groundwater use needs to be better monitored to improve our understanding and management of groundwater resources around the world.

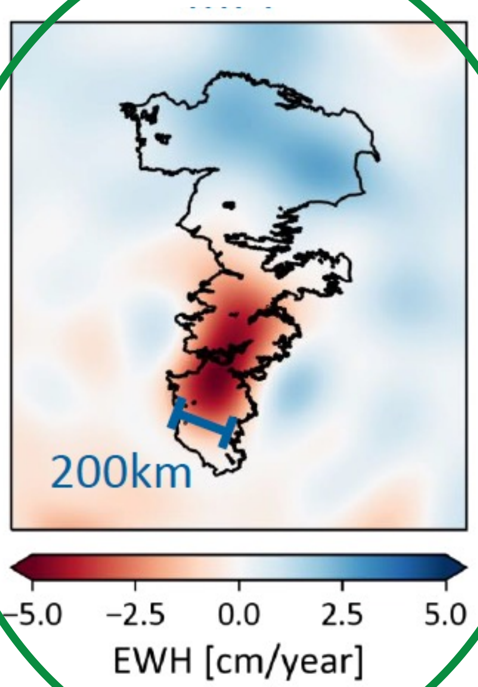
Improved spatial resolution of long-term water storage trends from GRACE/GRACE-FO data in small scale catchments and aquifers

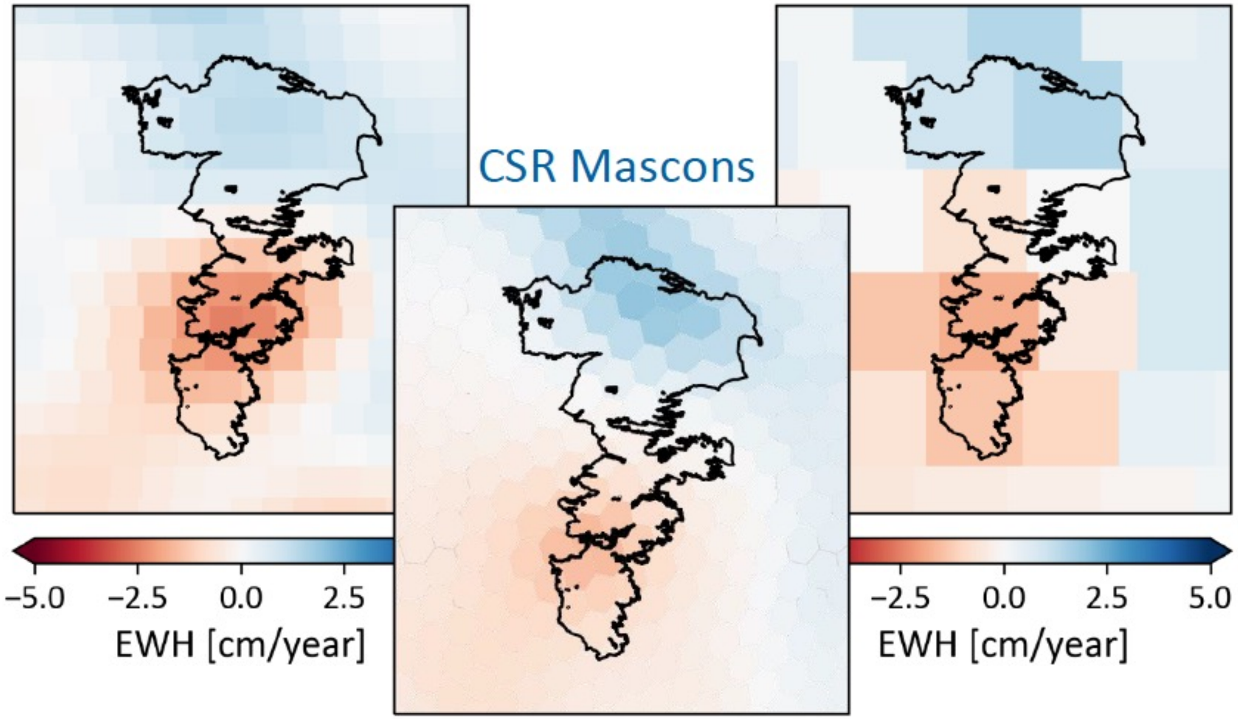


High Plains Aquifer

Resolution is improved by co-estimating trends with Long-term Mean Field







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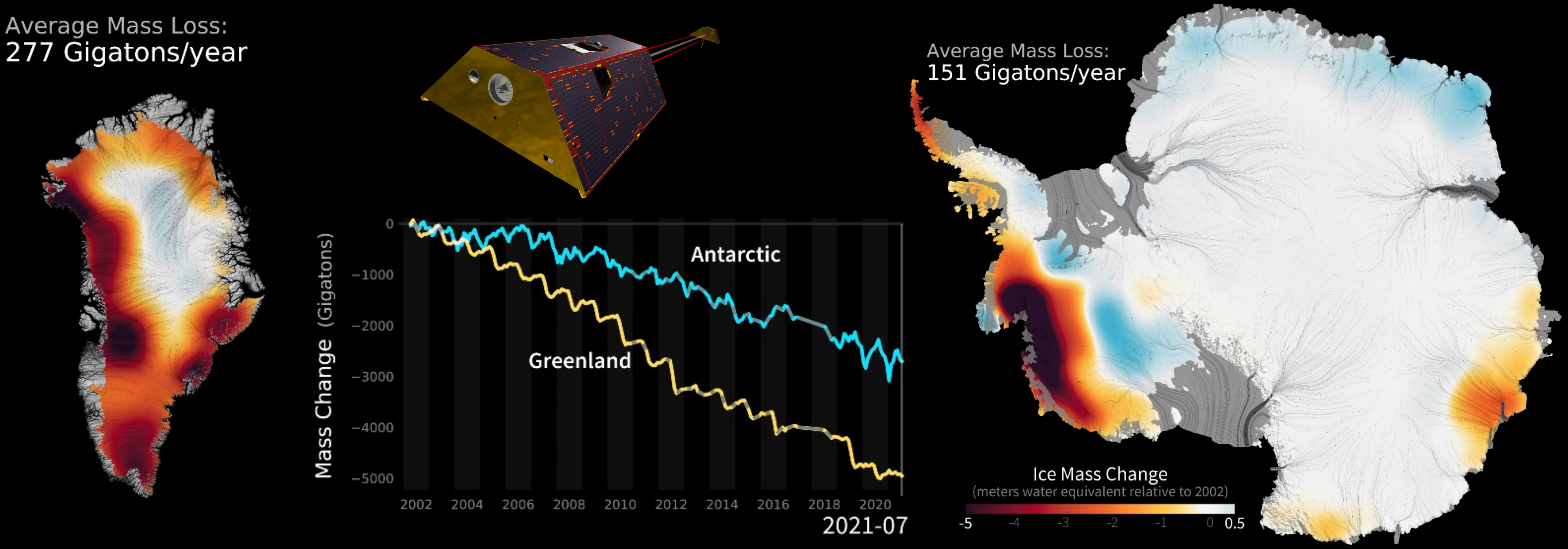
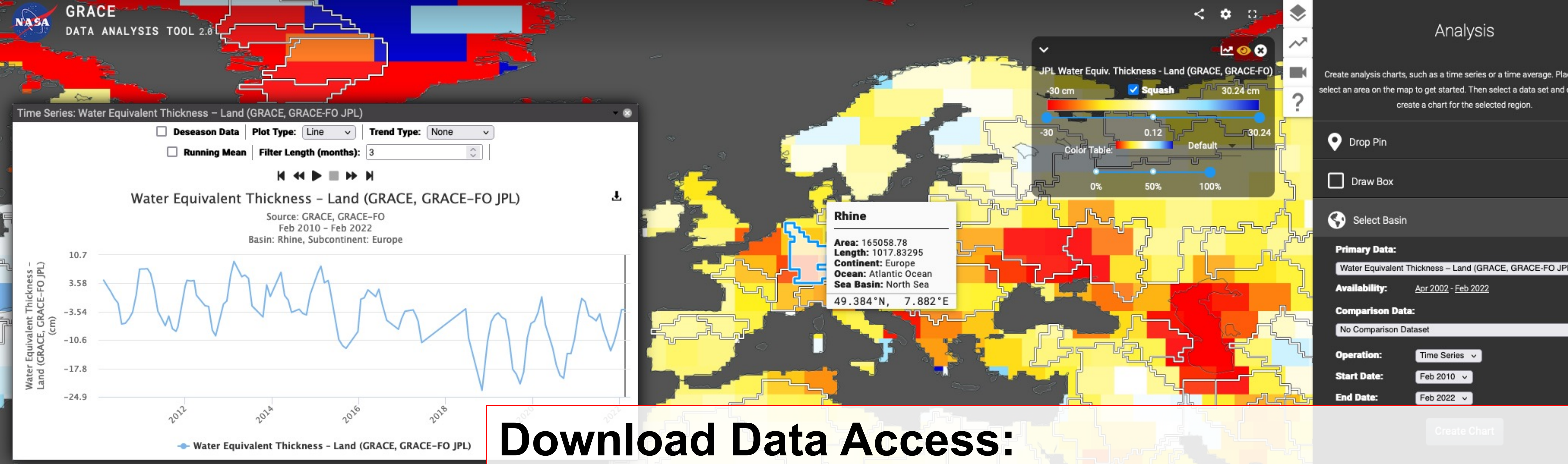
GRACE Follow-On: Observations of *Ice Mass Change*



Greenland's and Antarctica's ice mass loss since 2002 amounts to 7700 Gigatons, and has raised global sea levels by 22 mm.



Download Data Access:

- About <u>70%</u> of data users (>250/month) download <u>Level-3 & 4</u> GRACE/GRACE-FO data.
  - Note: JPL/NASA PO.DAAC, does not include deliveries from GFZ, CSR, and GSFC data centers

Interactive Data Access:

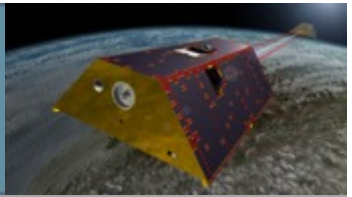
JPL - https://grace.jpl.nasa.gov/data-analysis-tool/

-> ***5140*** visitors in 04/2022

GFZ - http://gravis.gfz-potsdam.de/

-> **~2000 visitors** monthly from 75 countries

Science Performance & error levels



GRACE-FO:

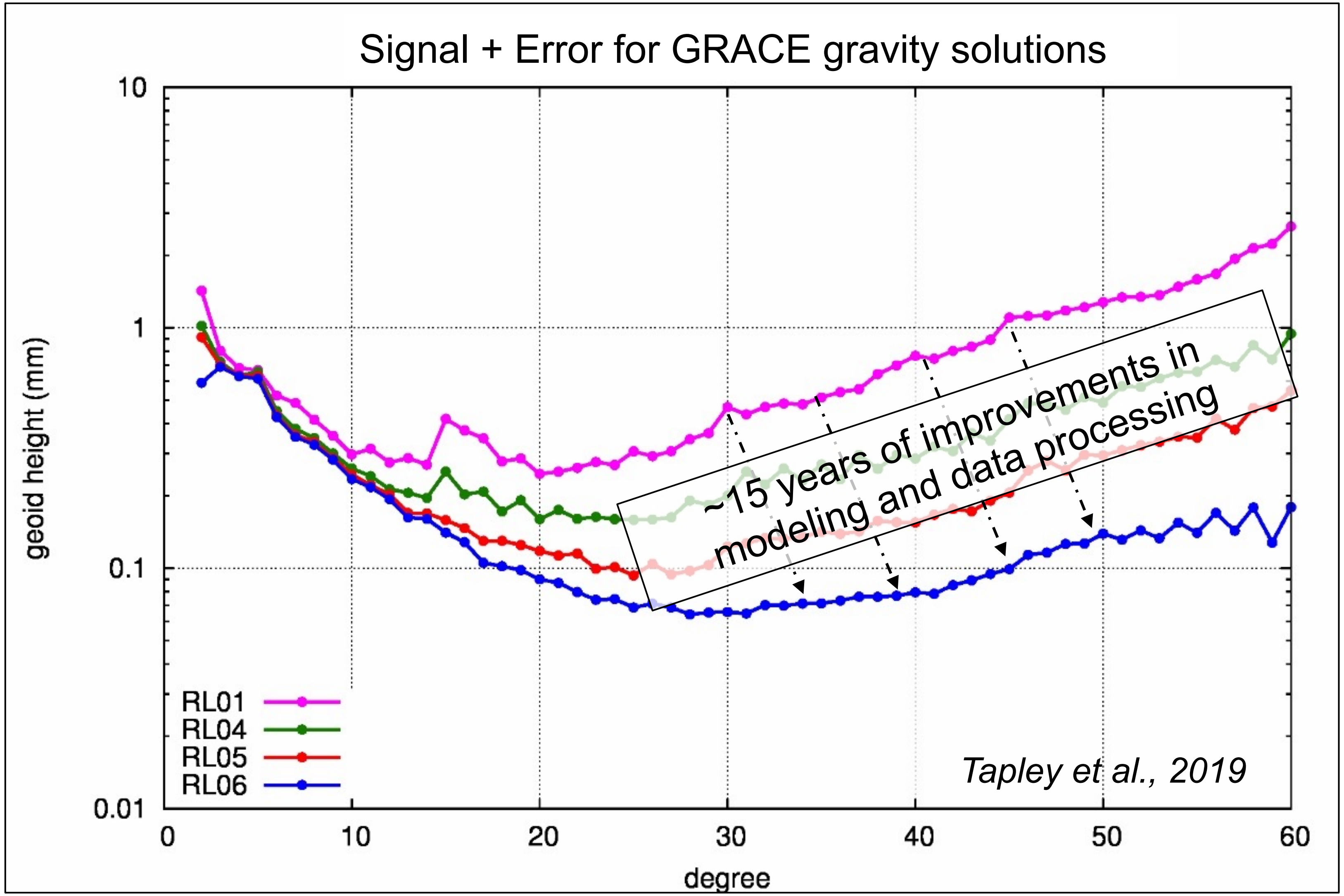
Status

Plans

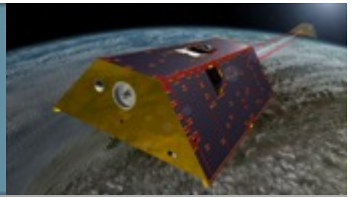
Outlook

Science Performance & error levels

The community is constantly improving the quality of science products through improved modeling of high-frequency mass variations coupled with improved data processing methods to improve the quality of the gravity fields.

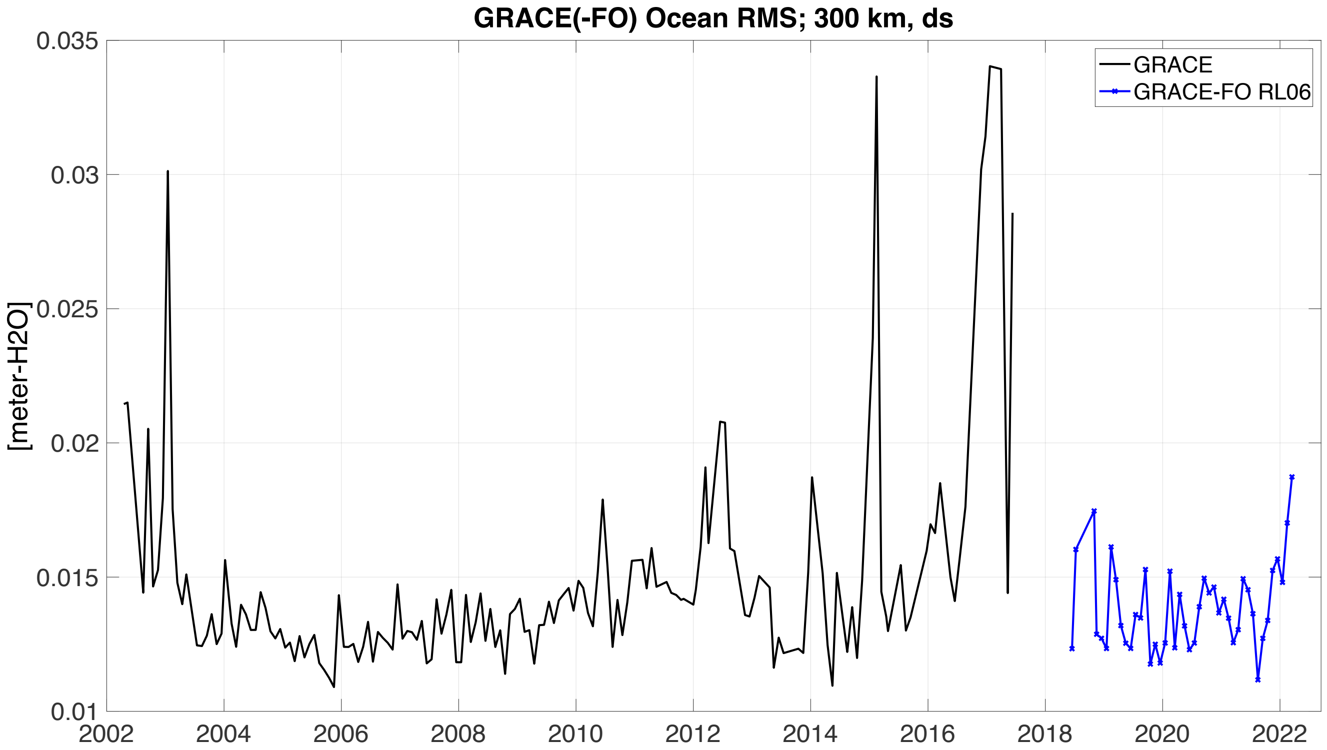


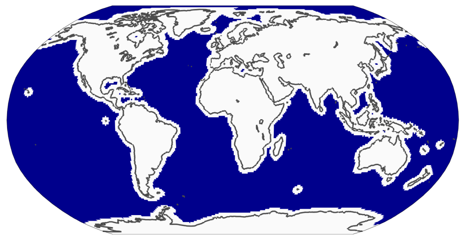
Science Performance & error levels
I: Ocean RMS



GRACE-FO Gravity solutions (**RL06**) continue to be on par with GRACE mission quality.

Ocean RMS: measure of error in the G/GFO monthly data





What is shown:
Error levels over the ***global ocean*** for **GRACE** (04/2002 – 06/2017) and **GRACE-FO** (06/2018 – 07/2021); RMS [meters-H2O] relative to a fit, removing trends and (semi)annual signals (the JPL RL-06 solution).

What it means:
Error levels over the ***global ocean*** for **GRACE** and **GRACE-FO** are consistent across the 19+ year Mass Change data record.

Science Performance & error levels
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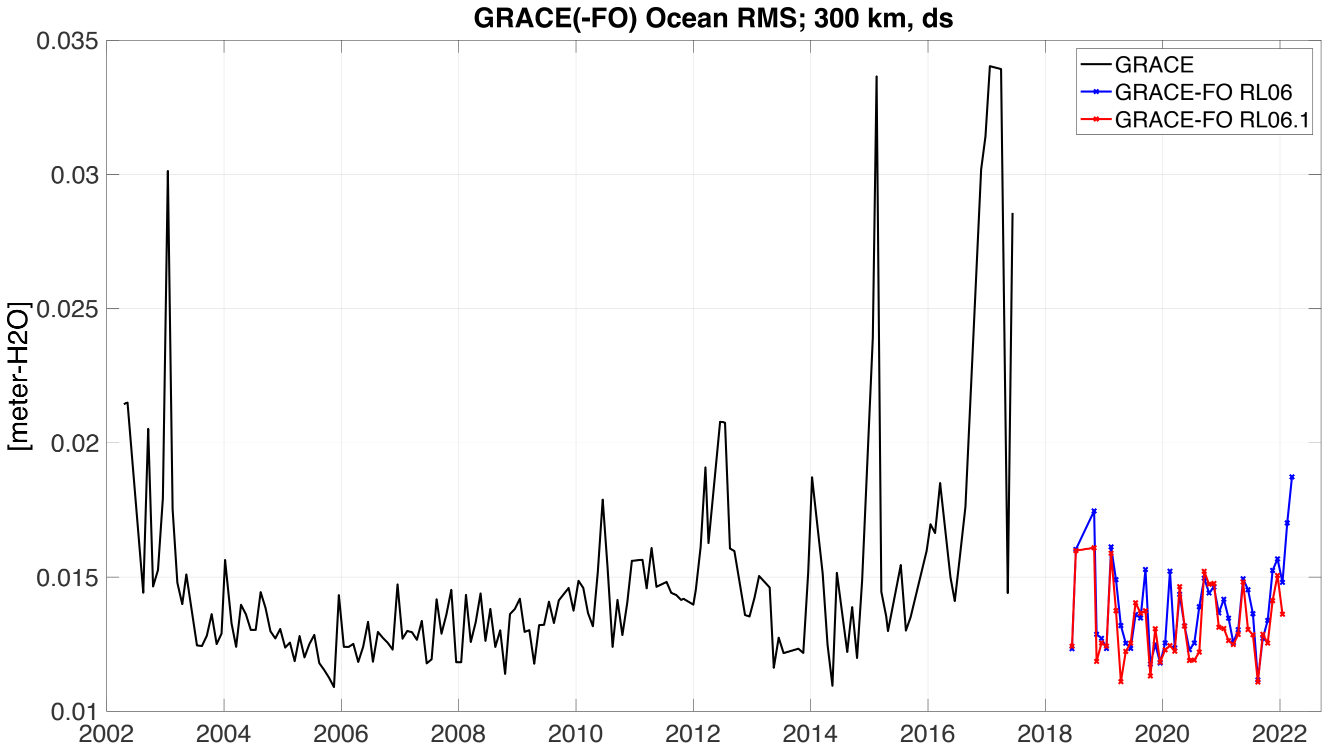

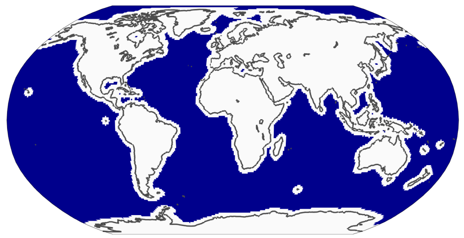

New GRACE-FO Release available: **RL06.1**

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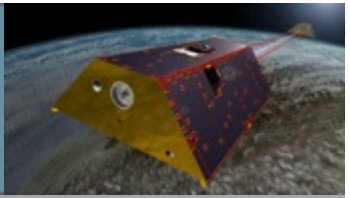

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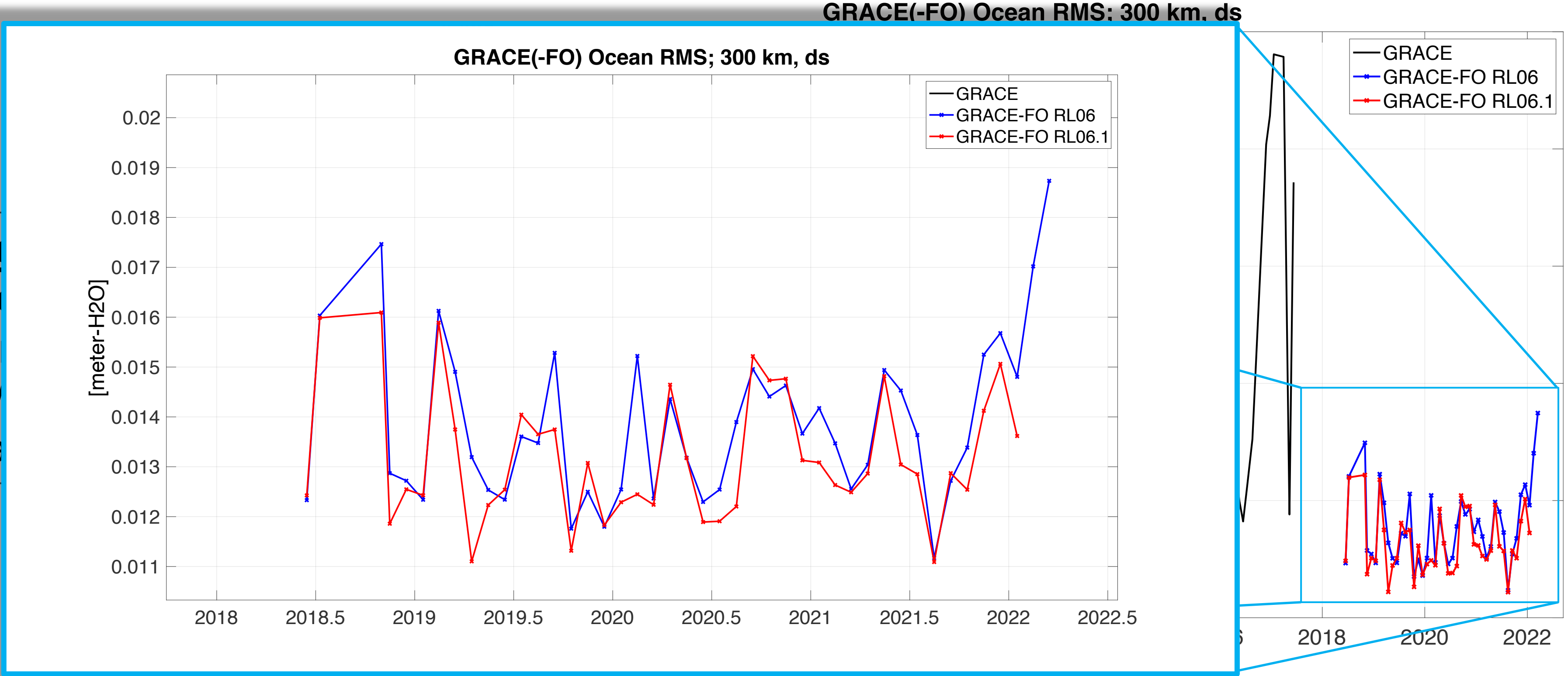
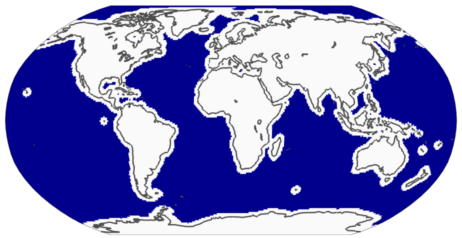




New GRACE-FO Release available: **RL06.1**
Hybrid ACC Transplant!

Error levels over the ***global ocean*** for **GRACE** (04/2002 – 06/2017) and **GRACE-FO** (06/2018 – 07/2021); RMS [meters-H2O] relative to a fit, removing trends and (semi)annual signals (the JPL RL-06 solution).

What it means:

Error levels over the ***global ocean*** for **GRACE** and **GRACE-FO** are consistent across the 19+ year Mass Change data record.

We now use GF2 ACC data (1-axis)!
What's the upshot here?

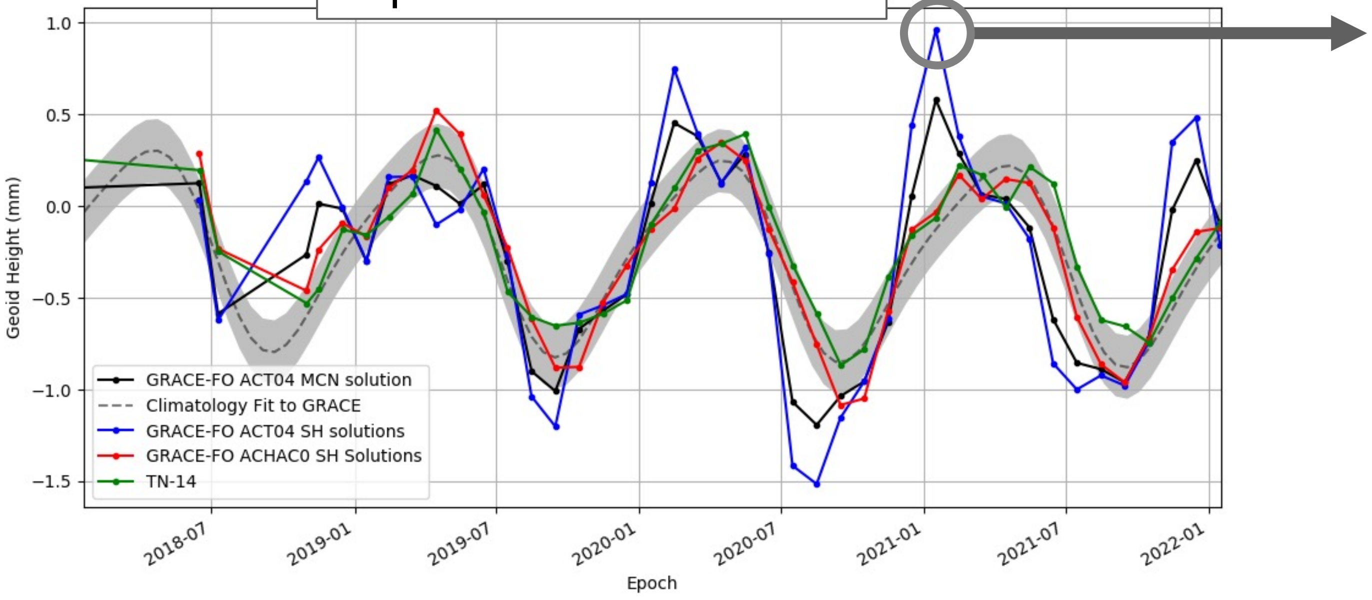
New Accelerometer transplant (ACH-L1B):

- New *hybrid transplant* is a ***GF2 ACC data-driven*** calibration (paper in prep.)
- Can better deal with non-gravitational force differentials between GF1 & GF2

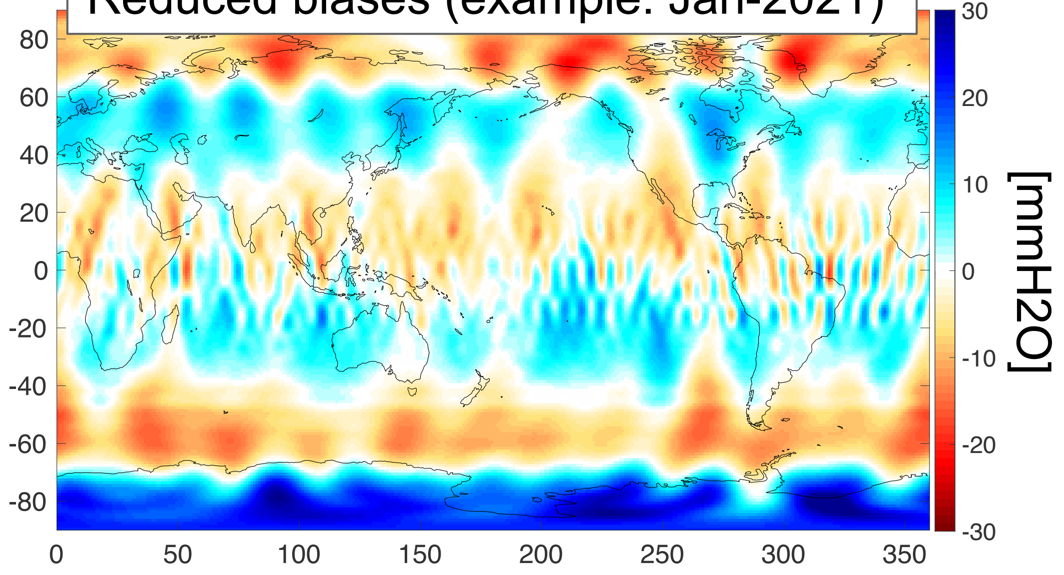
Impact on GRACE-FO data quality:

- Improved low-degree zonal harmonic coefficients (zonal coefficients)
- Reduced biases, especially high-latitude mass change fields (e.g., Antarctica)

Improved C30 retrieval



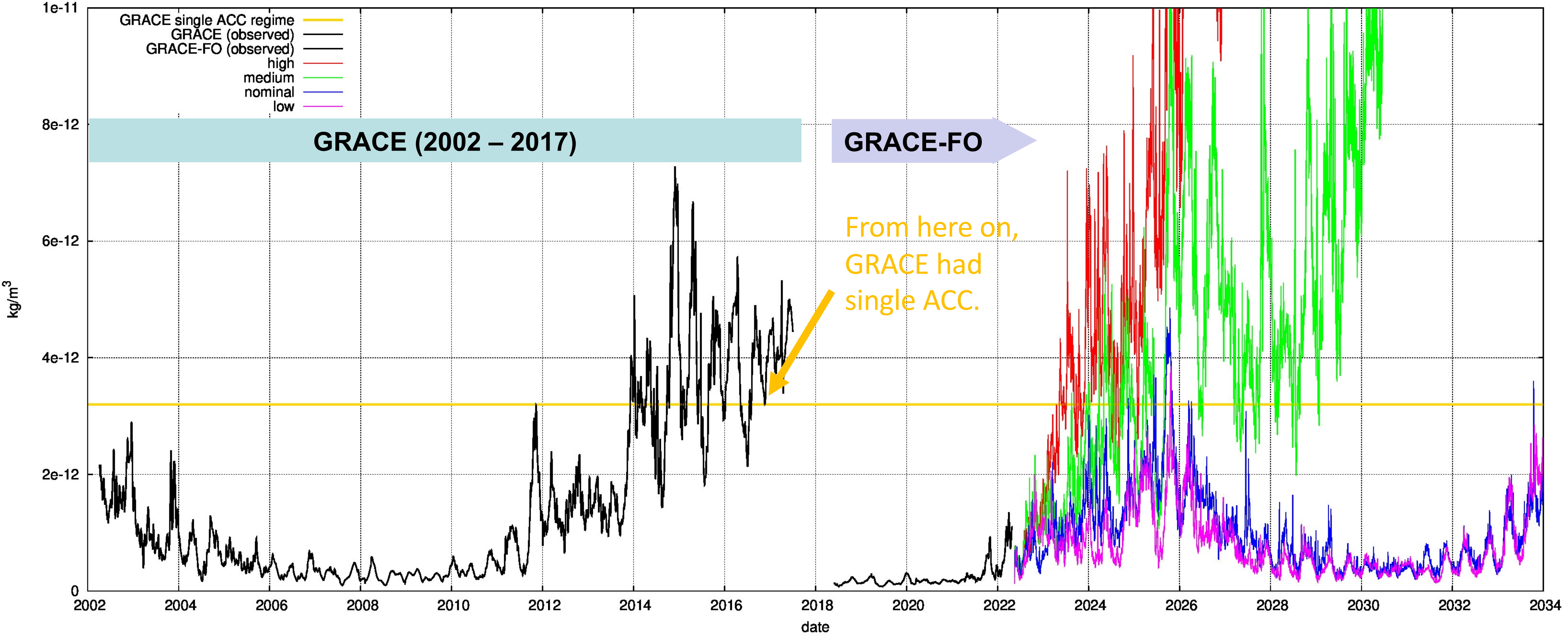
Reduced biases (example: Jan-2021)



Note: for now, GRACE-FO SDS has not changed the recommendation to replace C30 with TN-14 (SLR).

Looking ahead: Solar cycle #25 is ramping up fast …

Shown here: atmospheric density experienced by G/GFO satellites
(proxy for non-gravitational forces -> ACC measurement)



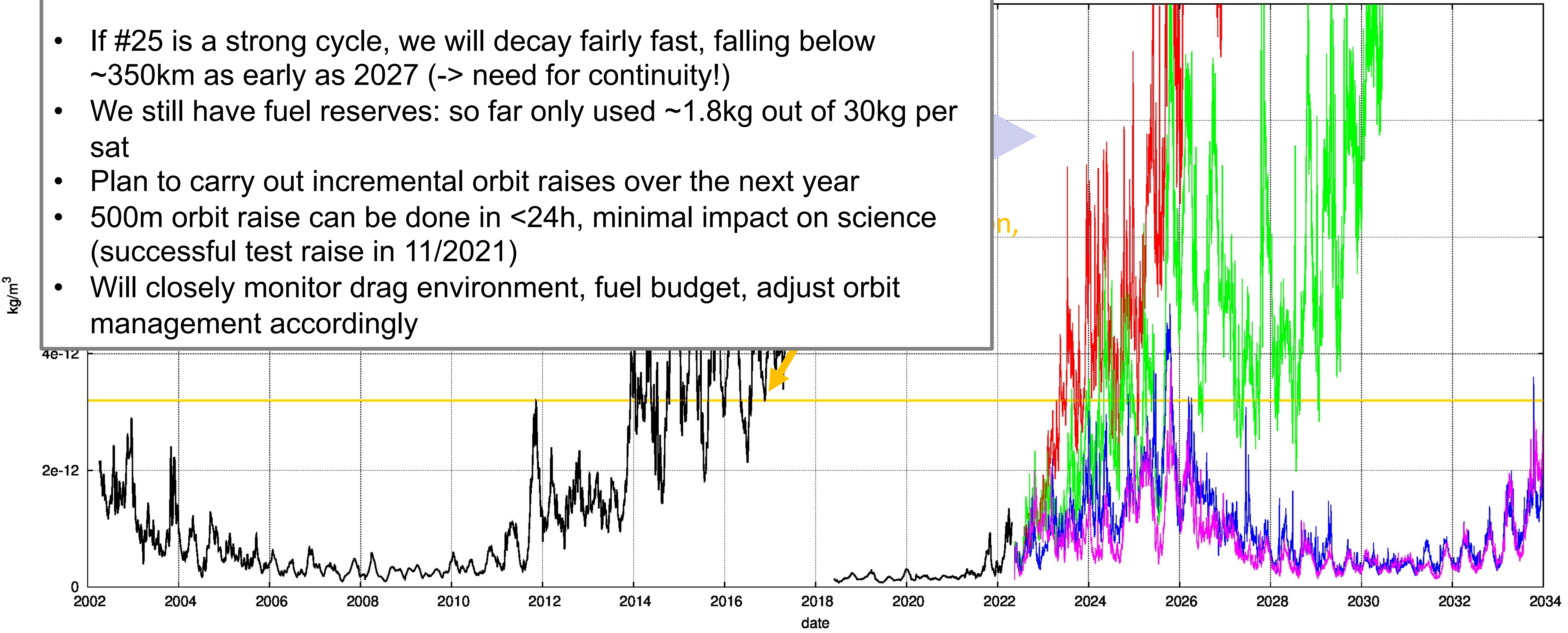
Looking ahead: Solar cycle #25 is ramping up fast …

Shown here: atmospheric density experienced by G/GFO satellites

easurement)

GRACE-FO near-term orbit management plan:

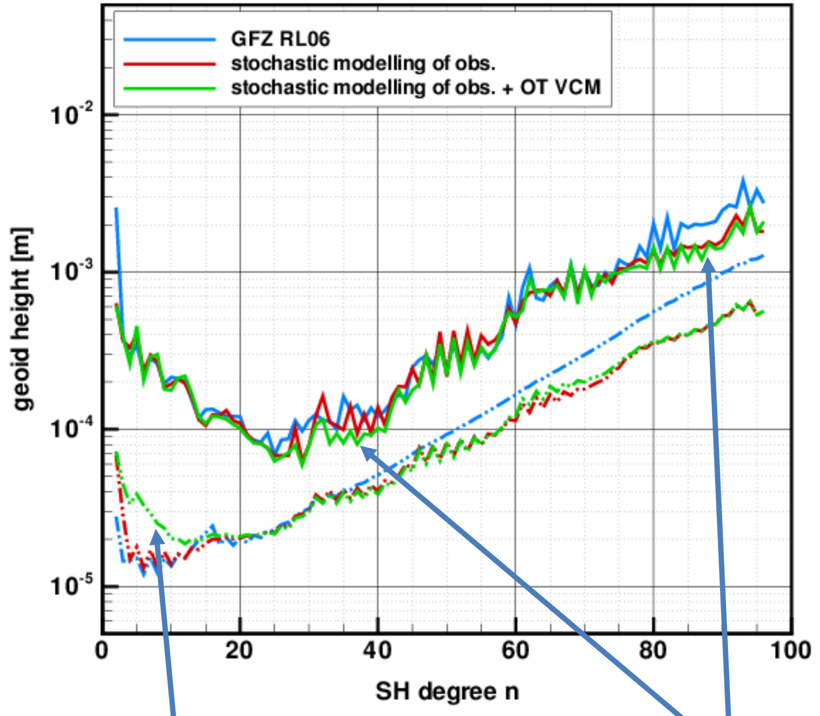
- If #25 is a strong cycle, we will decay fairly fast, falling below ~350km as early as 2027 (-> need for continuity!)
- We still have fuel reserves: so far only used ~1.8kg out of 30kg per sat
- Plan to carry out incremental orbit raises over the next year
- 500m orbit raise can be done in <24h, minimal impact on science (successful test raise in 11/2021)
- Will closely monitor drag environment, fuel budget, adjust orbit management accordingly



Advanced processing strategies for a next release of the GFZ GRACE/GRACE-FO time series

Significant Improvements relative to current operational GFZ RL06 time series by combining different new processing methods:

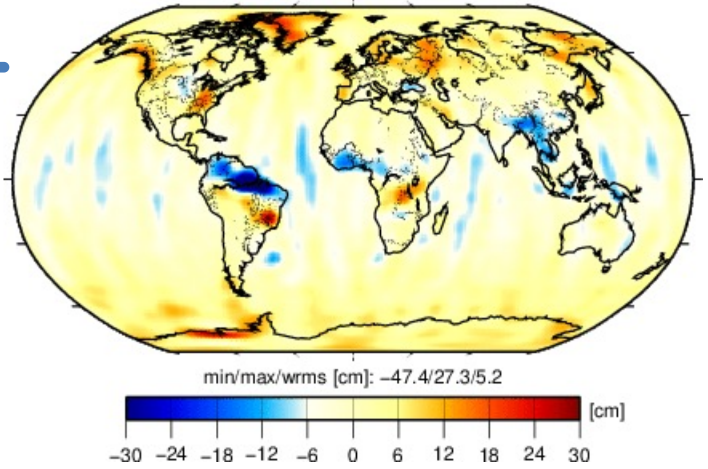
- Stochastic modeling of instrument data
- Stochastic modeling of ocean tide background model



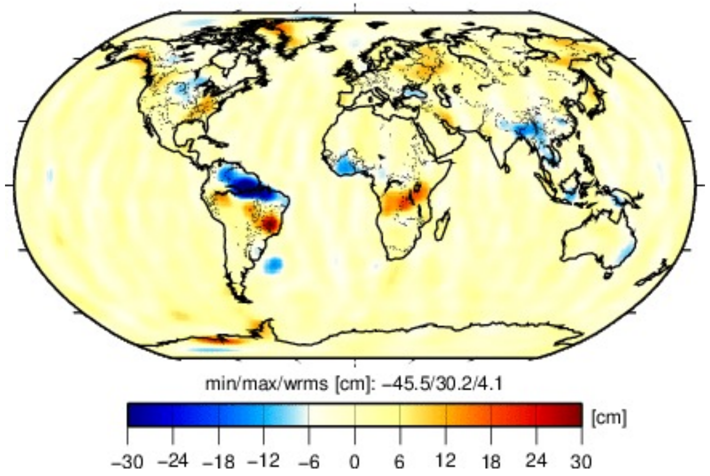
more realistic formal errors

less noise

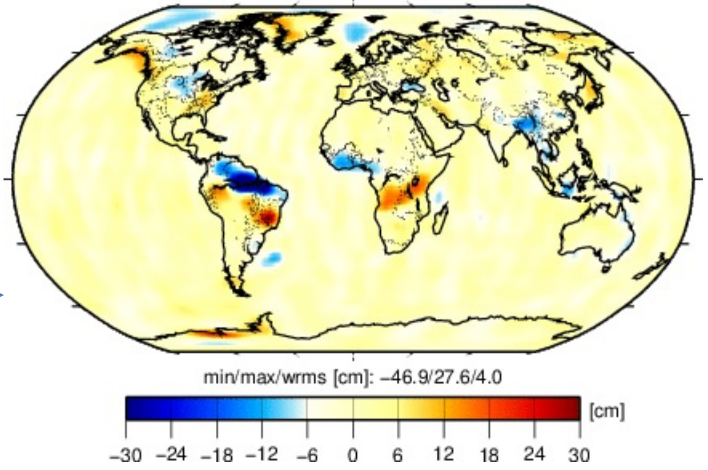
GFZ RL06
(ocean wRMS: 3.8 cm EWH)



Stochastic modeling of KBR
(ocean wRMS: 2.4 cm EWH)



Stochastic modeling of KBR + OT
(ocean wRMS: 2.2 cm EWH)

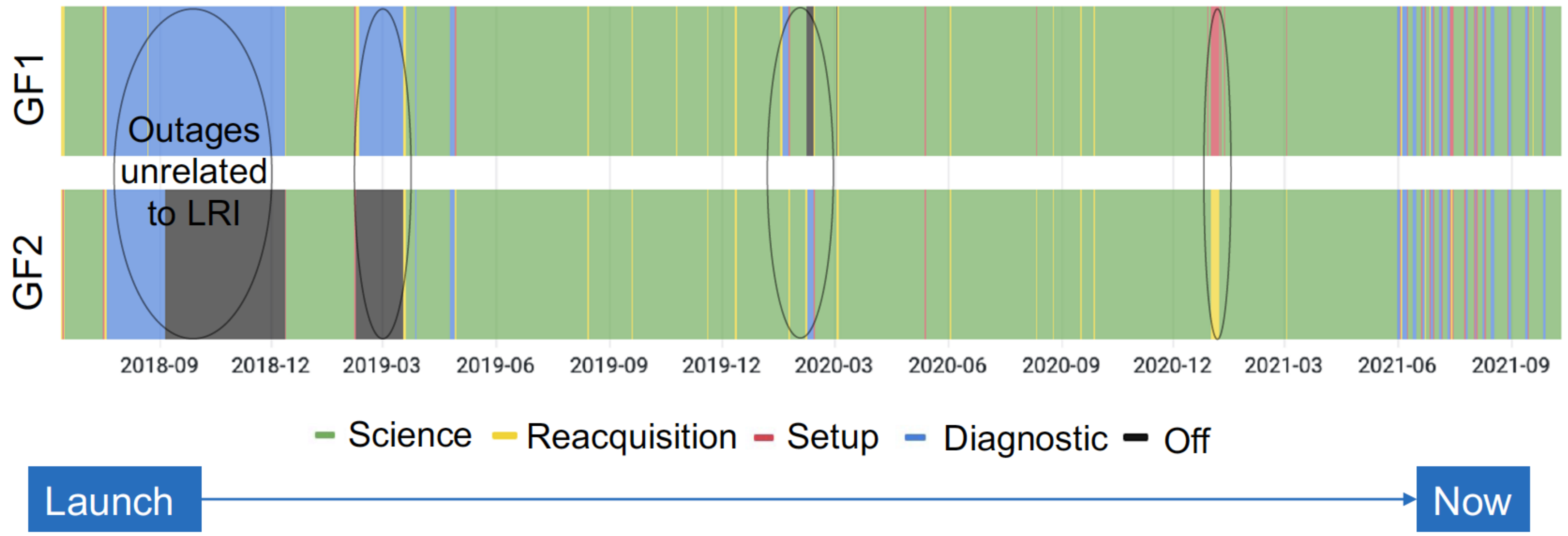


Example shown on this slide: January 2007 solution

Status - LRI Just Works (LRI is a technology demonstration on GRACE-FO)

In 2020, the LRI was in science >99% of the time (excludes intentional breaks)

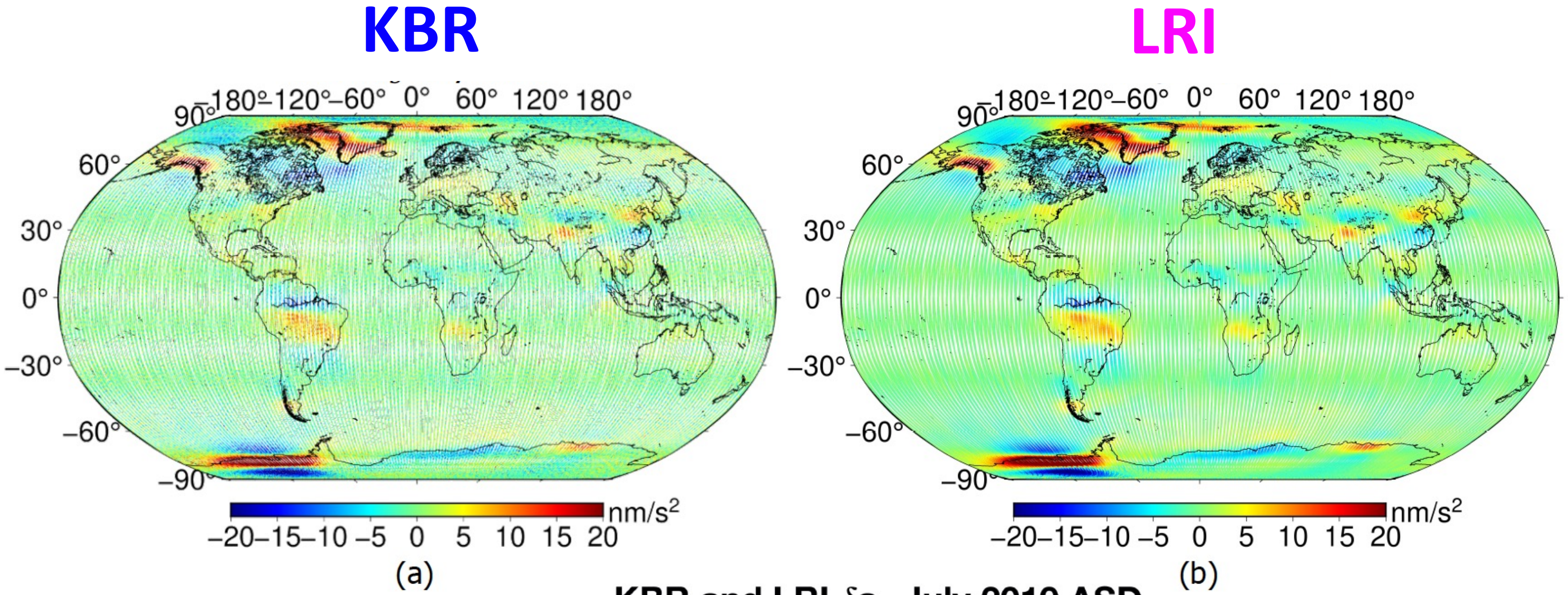
- *If laser link is lost, autonomous reacquisition typically recovers link within 30 [s]*

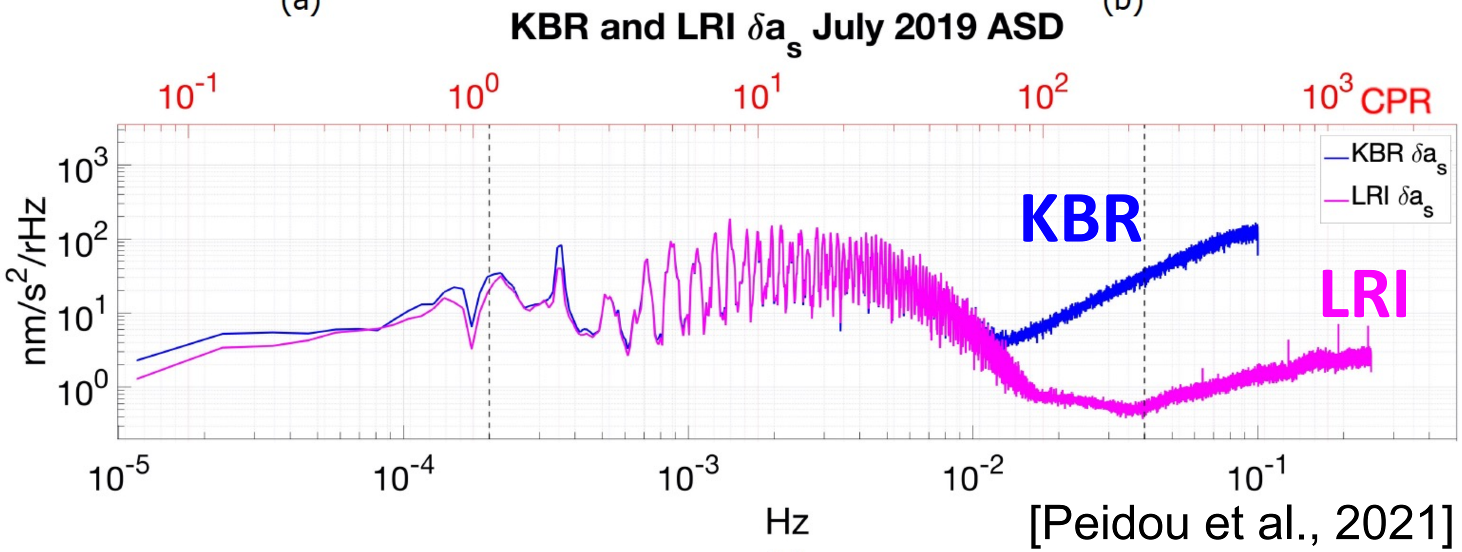


GRACE-FO: LRI vs KBR performance

- Broad agreement between between laser and K/Ka band ranging observations (not trivial)
- Significantly lower noise levels in LRI at higher frequencies (> ~10 mHz)
- Science Team is developing innovative applications (e.g., along-track analyses)

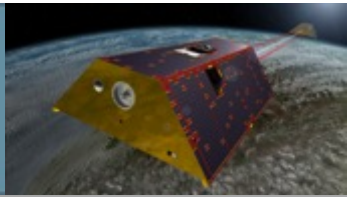
Range accelerations relative to static field (GOCO6s) for July-2019





[Peidou et al., 2021]

GRACE-FO Project Overview - Summary



- Continuous, stable data collection, processing & delivery
- Science data quality stable & on par with GRACE, meeting mission requirements
- GRACE-FO ACC transplant update uses GF2 ACC data & yields improvements, new RL06.1 data (L2 / L3) has been released
- Orbit maintenance considered to yield best science data quality (e.g., avoid very long orbit repeats, and avoid very high atmospheric drag)
- GRACE-FO has completed (nearly) 4 years of the 5-year prime mission
  - MOU extension signed between GFZ and NASA (extended through 2026)
  - NASA senior review early 2023 to extend prime mission
- **Overlap between GRACE-FO and next mission (MCM / GRACE-I, targeted for 2027) should have very high priority**
- **Next GRACE-FO Science Team Meeting: 18-20 Oct, 2022 @ GFZ, Potsdam**